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Stella Vosniadou (editor) (2008) *International Handbook of Research on Cognitive Change.* Routledge, New York. ISBN: 978-0-8058-6045-0, 740+xxviii pages, price: $103.46

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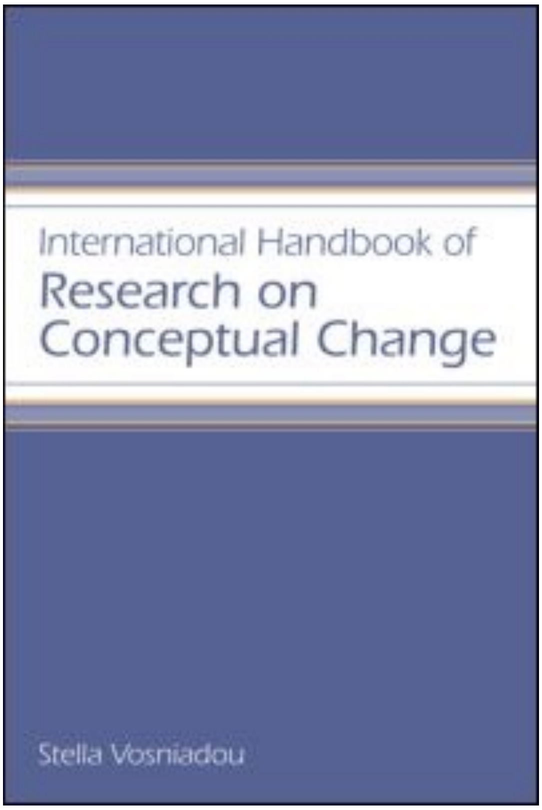

Stella Vosniadou has compiled an extensive set of chapters for this research handbook addressing the topic of conceptual change. For some, conceptual change is virtually synonymous with learning: it has certainly been a key focus of work in science education. Indeed science has often provided the context for those who are interested in enquiring into conceptual change. Perhaps this says something about the knowledge base typical of many cognitive scientists, or perhaps something about the nature of the natural sciences. The editor notes that "the roots of the conceptual change approach to learning can be found in Thomas Kuhn's work on theory change in the philosophy and history of science" (Vosniadou, 2008: xiii). It is certainly the case that understanding the nature of conceptual change, and how to encourage and direct it, has been a major concern in research in science education (Taber 2009). This *Handbook* will therefore be of interest to a great many working in science education.

The notion of an *International Handbook of Research* in any area carries with it certain expectations. One might expect that such a handbook offers the distilled wisdom in a field – the current state of knowledge, reported by the key thinkers in the field. In these regards, *this Routledge Handbook* scores well. The chapters included cover the key topics, and approaches, that would be expected. And certainly, many of the leading thinkers are represented among the authors. It is more questionable whether one might expect a handbook to be able to offer a strong synthesis of current knowledge. That is problematic in a topic area such as this: there are differences in perspective, and variations in the use and definition of key terms, that prevent any single book offering a clear consensus picture of the topic. Arguably, then, strong coherence would only be likely in an unbalanced book, or in a topic where it is felt that much of the indicated research has been done and there is less demand among researchers for a handbook: active researchers having moved on to new questions and topics. In this area of work, conceptual change, there is a choice between coherence and comprehensiveness. The area of conceptual change research is still a contested and messy one, and this book reflects that. And the need for such a book is greater for this.

Structure and organisation of the Handbook

There are 27 chapters in the book, each offering a substantive review of a key area or perspective, though often foregrounding particular studies considered by the authors to demonstrate the value of a key approach or set out seminal findings. Inevitably some chapters do focus rather heavily of work carried out by the chapter authors and their collaborators. Inevitably, and perhaps not unreasonably when authors have been selected by their contributions to the field. This is not problematic as there is a good balance across the volume as a whole. There is also a good deal of overlap of treatment, and cross-referencing among some contributors. Again this seems to be a fair reflection of the state of the field.

The book is organised into six sections. After an introduction by the editor, the sections are 'Theoretical issues in conceptual change research' (5 chapters); 'Conceptual change in the content areas' (7 chapters); 'Conceptual change in the philosophy and history of science' (2 chapters); 'Mechanisms for conceptual change' (4 chapters); 'The context and the learner' (4 chapters); and 'Instructional approaches to promote conceptual change' (5 chapters).

One key feature of the book of interest to readers of 'Science & Education' is that discussions conceptual change in science (albeit in most cases related to learners, not scientists) features heavily. Beside the section on HPS, many of the other chapters rely heavily on work undertaken into thinking and learning in science. As the author of one chapter note, "while there was an abundance of research being carried out within the natural sciences, the research on alternative frameworks within the humanities and the social sciences was languishing" (Halldén, Scheja, & Haglund, 2008: 512). So in the section about conceptual change in 'content areas', six of the seven chapters focus on 'science content areas': physics, astronomy, matter, naïve biology, evolutionary biology, and medicine and health – the exception being history.

The state of the field

Taking the book as a whole, it is possible to reflect upon the current state of the field of research into conceptual change. As suggested above, one obvious impression that Vosniadou's collections offers is of an area of scholarship that lacks strong unity and coherence. Given the Editor's references to Kuhn, one is tempted to label the field pre-paradigmatic. There certainly is not the suggestion of a community of scholars who are working within a disciplinary matrix, sharing norms relating to central concepts, preferred terminology, methodological paradigms, and so forth. Of course, one should not adopt a label such as 'pre-paradigmatic' unless it is considered certain conditions apply: specifically (i) that we accept Kuhn's model of science; (ii) we consider this area of work to be a part of science; and (iii) that we would consider this area of work to potentially offer the basis for a paradigm.

It can certainly be argued that research into topics such as conceptual change can be considered to be science, at least following a Lakatosian model (Taber 2009). Lakatos would acknowledge that competing research programmes can co-exist within a field over extended periods without a dominant paradigm developing to exclude its competitors (Lakatos, 1970).

However, whether 'conceptual change' is the type of focus around which we might expect a distinctive field of research to be organised is an open question. There are concepts in the natural sciences that are treated differently within different disciplines, without bringing into question the mature status of the disciplines concerned. For example, the way in which concepts such as 'acid' and 'acidity' are understood in chemistry and pharmacy (Sainsbury 2009), relate to the different foci and ultimate purposes of scholarship and research in those disciplines, and do not suggest either are 'pre-paradigmatic'. Perhaps 'conceptual change' offers a similar case, and this book should be seen as offering insight into how the concept is understood and researched in distinct disciplines (such as cognitive psychology, history of science, science education, etc) without considering it to be the focus of a distinct subfield in its own right.

The question of what might be considered as a subfield of scientific inquiry, the within-science demarcation question, is certainly a relevant issue in terms of the present volume, where work in conceptual change has been addressed from a number of perspectives. Those primarily concerned with the historical shifts in scientific thinking naturally focus on professional 'experts', whereas much work on conceptual change has looked at young children and school/college students. Within this work on learners there are researchers who approach the topic as psychologists and cognitive scientists (often identifying maths and science concepts as suitable topics for their research) as well as science educators who often have subject expertise and professional experience in science teaching/learning contexts, and who are ultimately concerned with the teaching of domain knowledge within the curriculum subject, but may have less expert knowledge of the psychological frameworks for thinking about cognition, learning and development. One of the strengths of the present volume is its inclusive nature, with science educators well represented amongst the contributors. However, the different backgrounds (and so professional training) is significant if we consider Kuhn's model of how scientists become inducted into a paradigm.

Elsewhere I have agued that when considering the field of science education, it is possible to identify a hard core of common assumptions underpinning a good deal of work into learning and teaching in science, to the extent that that work can be considered to fit within a common research programme (Taber 2009). From that perspective (constructed from within a Lakatosian framework) it is possible to see debates about how conceptual change occurs, and related questions about how best to model student knowledge as driven by a positive heuristic within a progressive programme. That is, that when considering research into learning in science (and how to facilitate it) different models of cognitive structure and conceptual change may be considered alternative refutable variants within the 'protective belt' of theory that gets built around hard core assumptions.

The present volume encompasses the themes of much of the work considered in that analysis, yet when the focus shifts from learning in science to conceptual change *per se*, it becomes harder to recognise coherence within the wider research effort. In part this may be an issue of resolution or 'grain size' (conceptual change magnified from one theme among many, to the core issue). One key issue about the nature of teaching and learning, which has certainly been to the fore in science education, has been the extent to which a focus on the individual learner can only ever be partial, as teaching and learning are social processes. A sociocultural perspective has certainly been in the ascendancy since Vygotsky's work became popular in Western educational thinking. As with so many ideas and constructs introduced into discussions of learning, this can mean different things to different people. If a focus is on school learning, then it is clearly foolish to ignore the presence of other epistemic beings – teachers, peers – in attempting to understand learning processes. The role of the teacher in institutionalised enculturation, the existence of target knowledge in the form of curriculum, the interactions with other individuals through such symbolic tools such as verbal language, and artifacts such as tests-tubes, protractors and posters of the periodic table, are all clearly relevant to learning (or there would be little point in schooling).

Some approaches to considering cognition in terms of the mind as part of a situated system seem relatively uncontentious. So, for example, Nersessian's (2008: 405) suggestion that a full understanding of human memory would "encompass external representation and cues" does not undermine the notion of individual cognition. The extent to which such matters are moved from part of the 'field' (i.e. part of the learning environment) to be the 'figure' in research is a principled and methodological decision. So whether the level of analysis is the individual within a social setting, the dyad or small group, or the class, will depend upon the researcher's basic ontological and epistemological commitments - as well as their particular research questions (which of course will themselves be heavily influenced by such commitments). Moving the focus further towards the social level may sometimes seem to require a new way of talking and thinking about classroom learning. The class may become a community of practice; teaching may be seen in terms of discourse practices, and learning as participation in such practices. Perhaps representing this complex phenomenon symbolically through triangles of 'activity' may even encourage some researchers to see knowers, knowledge, teaching, tools, etc as ontologically similar components of a social system. The individual may come to seem less salient than the activity that takes place on the social, intra-personal plane, and – taken to the extreme - ultimately personal knowledge may cease to have a role in the account of learning. There is a real area of debate here, and the editor clearly believes a line must be drawn beyond which shifts toward the social perspective cease to be useful: "students' difficulties in learning the concepts of current science and mathematics have been documented in hundreds of studies and represent one of the mot pressing problems of schooling. They are not going to disappear because they are not consistent with the radical sociocultural perspective. Rather it is the sociocultural perspective that needs to be modified to allow for the possibility to objectify knowledge" (Vosniadou, Vamvakoussi, & Skopeliti, 2008: 25).

The key here would seem to be to be able to take a view of the social without loosing sight of the individual: for as we are reassured in one chapter of *the Handbook* these approaches can be 'complementary' (Miyake, 2008: 460). At the risk of over-stretching the optical allusion, what is needed is not a refocusing away from the person to the community, but rather developing instrumentation – a methodological panopticon perhaps - with sufficient depth of field to keep both aspects under inspection.

A number of contributions to *the Handbook* do explore perspectives on this continuum, and Leach and Scott (authors who always seem to be able to synthesise the theoretically supportable with the practically useful) offer a helpful overview of related ideas. In particular, they offer a very pragmatic reason for adopting some shift away from the focus on individuals that was at the core of Piagetian work where "science teaching for conceptual understanding is therefore viewed as a process of supporting learners in *personal construction* of knowledge based on experiences of natural phenomena, rather than a *guided introduction* to ideas that already exist within a community" (Leach & Scott, 2008: 649). Leach and Scott are absolutely right, in that the former view, if adopted myopically, leads to a naïve version of discovery learning that has long been discredited. Their approach does not deny the individual student's personal knowledge, but reminds us that schooling is intended to mould such knowledge in normative ways through social processes.

That said, Vygosky's often quoted claim that the formation of concepts always takes place at the interpersonal level before it can occur at the intrapersonal level (Vygotsky 1978) has perhaps acquired the statement of a dogma among some adopting the sociocultural perspective, that is neither justified by our personal experience of learning, nor by a broad reading of Vygotsky himself. Vygotsky's own distinction between spontaneous and scientific concepts seems to make it clear this is not how he intended his ideas to be taken: rather that the development of an individual's spontaneous concepts *towards the consensual 'scientific' models of the culture* was necessarily mediated by interaction with those already possessing that cultural capital.

Conceptual change, cognitive development and learning

A central question is what is actually meant by 'conceptual change', and how does it relate to other constructs such as 'cognitive development' and 'learning'. *The Handbook* suggests that this may not be such a straightforward question, as various criteria for, and typologies of categories of, conceptual change are presented in different chapters (e.g. Chi, 2008; Inagaki & Hatano, 2008; Keil & Newman, 2008; Linn, 2008; Schwartz, Varma, & Martin, 2008; Thagard, 2008).

Jean Piaget (e.g., 1972) famously offered a model of cognitive *development* as occurring in stages, and involving the acquisition of broad cognitive capacities that could be applied in various contexts. Piaget considered himself to be a genetic epistemologist, and saw the individual children and adolescents he investigated as examples of the epistemic subject - as he was interested in how people typically came to acquire the cognitive apparatus for developing knowledge. The epistemic subject can be seen as some kind of Platonic ideal, and the idiosyncrasies of (real) individual developing young people as offering (if not noise in the data) almost epiphenomena from which the analyst had to identify the general underlying pattern. Piaget was interested, then, in cognitive 'development', the normal process of growth in cognition of a typical person regardless of specific learning opportunities. Piaget is not currently considered to offer the most productive way of thinking about conceptual change issues: he is certainly mentioned in *the Handbook*, but usually in a parenthetical or critical manner.

Although much of Piaget's model has been abandoned by many researchers, and the assumption that focusing on domain-general cognition is a useful and meaningful project has been widely questioned, the notion that key aspects of becoming a normal thinking adult follow a general pattern that is largely biologically determined and will unfold in a wide range of specific circumstances is certainly strongly supported. Work with newborns shows a good deal of inbuilt cognitive apparatus, and the brain seems to undergo certain patterns of development under largely genetic control during our extended human maturation (Goswami 2008). These processes are akin to what is found in many other species and seen as instinctive (no one has to teach a mother bird to feed its chicks), and in some ways similar to learning to walk. There will be environmental conditions that may delay or even prevent normal development, but notions of teaching are not really relevant.

Learning, however, is rather different to development. People are not born set with specific priming to learn that Geoff Hurst scored a hat-trick in the 1966 World Cup final, or that the internal angles of a triangle sum to 180˚, or that helium has two common isotopes. Rather these are things that have to be learnt. This may seem a trivial point, but the distinction between development and learning does not seem to be an absolute one. Seeing our mental apparatus as some kind of neutral processing unit, some kind of ideal Turing machine that will undertake unbiased computations for us, would be a mistake. Our cognitive apparatus is the outcome of extensive evolution, and has built in biases that are due to what has worked well over most of human evolution (Sweller, 2009). However, much that we want to use our cognitive faculties for in the twenty first century (whether balancing our bank accounts or balancing chemical equations) was not a priority for the vast majority of the period over which those biases developed. Such biases works really well for some things: we seem to be born ready to recognise faces (very useful for a baby), and ready to learn to see the world as made of discrete objects which take up exclusive use of space (very useful to understand building bricks, not so helpful for understanding orbital overlap in models of chemical bonding). Quite where development stops and learning starts is not always clear.

Conceptual change is a central issue for those interested in learning. In the educational context, many curriculum targets can be understood in conceptual terms. Young people may be expected to learn about the difference between elements and compounds; how water is recycled in nature; why metals conduct electricity; how to identify the anion present in salts; and a great many other things. Young people do not enter school knowing these things, and – just as significantly – they usually come to class (at least in science, and probably in most academic subjects) holding a wide range of ideas that are not entirely consistent with target knowledge (Duit, 2009; Taber, 2009). The teacher's role then (at least in part) is to facilitate conceptual change – so that the child starts to consider gases as material when they had not previously; looks for causes when moving objects slow and stop rather than see such change as natural; considers diseases in terms of material agents, rather than perhaps in supernatural terms; and so forth. We might hope that a handbook on conceptual change can help us pitch curriculum at the right level; design instruction to support teaching; and inform teachers how to bring about such conceptual changes. That is likely to rely, of course, on a good grasp on what conceptual change actually involves.

What is changing during conceptual change?

A mature science of conceptual change would provide us with a pretty good idea of what actually happens during conceptual change, and how those changes can be influenced by learning environments and teaching. Yet the reader of *the Handbook* will not get definitive answers to such questions, for "we still need to address an enormous gap that remains at the core of conceptual change theory: we do not have an adequate cognitive model of the basic conceptual change process; we do not have a good understanding of how flexible models are constructed…What is missing is a fuller specification of *mechanism*s of change – causal descriptions of processes that produce conceptual change" (Clement, 2008: 417).

Given 'conceptual change' as a focal construct, a key issue becomes what actually changes during conceptual change. The trivial answer 'concepts' allows the suggestion that "true conceptual change occurs under one of two conditions: either a concept's internal structure changes, or its relations to other concepts changes in ways that are central to its meaning"(Keil & Newman, 2008: 83). Yet such a response also invites the follow-up question of 'what are concepts' – itself an issues that remains the subject of ongoing scholarship and research, as recognised in *the Handbook* (White and Gunstone 2008). Concepts may, for example, be seen primarily as classifications – whether based on definitions, key membership criteria, similarity to prototype members etc – or may be seen more as nodes in relational nets, a kind of intra-mental concept map (Gilbert & Watts, 1983).

A complication here is that we are actually dealing with two ontologically very different notions of concept. Scientific concepts - what Popper (Popper 1979) might consider World 3 entities - such as momentum or photosynthesis are largely defined in formal terms, but personal concepts (subjective, World 2 entities) are quite different. The teacher is charged with helping students 'acquire' world 2 concepts that when expressed publicly are judged to be similar enough to their third world referents (and judged of course, in terms of the subjective personal concepts of those previously judged to have obtained the desired concepts by the same indirect process). That World 2 objects can never be *directly* compared with World 3 objects (or even someone else's World 2 concepts) makes the whole business inherently problematic (Taber 2009).

Researchers are inevitably, then, in the business of building models. They model the nature of personal concepts, they model the 'conceptual structure' in which they consider them embedded in minds, and they model the cognitive processes by which they might be changed. Despite recent promising advances in neuroscience, work on conceptual change is primarily and substantially about minds, not brains. The objects of study are not neurons, neural circuits, synapses, excitation patterns, neurotransmitter levels or other 'world 1' entities (which many reasonably assume underpin mental activities), but rather naive theories, mental models, alternative conceptions, and so forth. In other words, researchers are building models of hypothetical entities and structures that can never be shown to actually exist, but can only be demonstrated to offer good explanations of indirect evidence (such as talking, writing, gesturing etc) of cognition.

Not surprisingly then, research and scholarship in this area is littered with constructs which often lack consensual meaning or adoption. Within science education, learners' ideas are often denoted as misconceptions, intuitive theories, alternative conceptions, or alternative frameworks, and so forth (Abimbola 1988). Although different authors may well have good reasons for preferring particular terms in the context of particular studies, there is no generally agreed usage across the literature (Taber 2009). Similarly, the reader of these different reviews of research into conceptual change will meet, *inter alia*, framework theories (Vosniadou et al., 2008), knowledge-in-pieces and intuitive mental ecologies (diSessa, 2008); ontological trees (Chi, 2008); naïve theories and naïve models (Brewer, 2008); mental models

(Nersessian, 2008); outcome spaces (Marton & Pang, 2008) and so on. Most of these approaches are based around modeling some aspect of what is going on inside minds: the models, conceptions, that are considered to 'exist' as an individual's mental representations of the external world perceived, experienced and imagined. So "the study of conceptual change encompasses a rich and diverse set of mental phenomena: sometimes dramatic conceptual change may underlie a sea of apparent conceptual calm while, at other times, a surface of marked conceptual change may derive from other sorts of changes in processing" (Keil & Newman, 2008: 99).

An exception is the phenomenographic approach that offers "a distinct ontological and epistemological position" (Vosniadou, 2008: xxiv), that suggests that "it might be more interesting to know what the learners can 'see' or experience than what they have in their minds" (Marton & Pang, 2008: 541). It is questionable to what extent this really avoids the methodological issues that complicate this area of work. Unlike the classical behaviourists, who eschewed study of mental events to focus on observable behaviour, phenomenographers cannot directly access what people see or experience any more than what they think or remember. Arguably, people can only report what they see or experience by representing in behaviour (such as speech or drawing) how they have mentally represented those perceptions and experiences. By default, then, research into conceptual change necessarily involves building models of the aspects of other people's minds (Taber Forthcoming). There is a sense here of needing to adopt something of a critical realist stance, if not an instrumentalist one. There is also the need for what is referred to in one of the contributions to *The Handbook* as a principle of charity, "that the researcher, to makes sense of individuals' ways of acting on a particular situation has to assume that these actions rely on a certain degree of coherence and cogency. In other words, the researcher has to assume that it is possible to understand other individuals…this implies that individuals, to some extent, overlap in how they view the world, and that this shared world-view enables intersubjectivity and mutual understanding" (Halldén et al., 2008: 520). At one level, of course, this parallels the metaphysical assumptions of many physical scientists that the universe is lawful, and has fixed underlying principles that humans can at some level understand.

Various models are discussed in this volume. The editor works with a model based around key domains of human experience giving rise to framework theories with their own ontological and epistemological commitments, and suggests that "it appears that at least four well-defined domains of thought can be distinguished and considered roughly as 'framework theories' – physics, psychology, mathematics, and language" (Vosniadou et al., 2008: 16). Yet this approach appears to be contradicted by another contributor who suggests that "popular concepts of life, mind, and disease are tightly intertwined: God created both life and mind, and can be called upon to alleviate disease. Hence conceptual change can require not just rejection of a single theory in biology, psychology, and medicine, but rather replacement of a theological world-view by a scientific, mechanist one" (Thagard 2008). Another approach divides up the mental world rather differently, in terms of distinct ontological trees for entities, processes, and mental states (Chi, 2008). Another view considers knowledge, even expert knowledge, as consisting of a collection of pieces that are "not monolithic, homogenous, and logically consistent" (diSessa, 2008: 47). One approach sees conceptual change as less about changes in the available concepts, but more about shifts in which of these resources are cued in different contexts so that "children and adults differ not in the underlying conceptual structures but in the relevance of these structures; children often posses several theories available to them early on, but they differ remarkably from adults in realizing where these theories are relevant" (Inagaki & Hatano, 2008: 259), perhaps because "as conceptual knowledge in an area becomes more articulated and richer, the child starts to appreciate more and more of its explanatory power for a wider range of phenomena" (Keil & Newman, 2008: 96). An overview of these disparate approaches, models and perspectives, suggests the value of the conceptual ecology metaphor (which is explicit in some of the contributions), as the reader is left feeling that the conceptual environment is complex, and its potential inhabitants diverse.

This leaves a lot of questions. Which of these models are right (even if we mean 'right' in a purely instrumentalist sense)? Are they all right, in different learning contexts, and should we be asking when each is right? Could there be a grand synthesis that will encompass currently championed ideas as different facets, or perhaps current models should be seen as first-order approximations, which will converge over time onto a final theory? In truth, this is a fascinating field, and the sense of incompleteness and degree of openness to further research makes it a very exciting one. However, that might also suggest that *the Handbook*, whilst invaluable to the research community, is rather premature for those actually designing curriculum or preparing teachers. The editor seems to accept such a view: "Researchers have just started to understand and explore the full implications of the conceptual change approach for the design of curricula and instruction. In addition there is a vast gap between our theoretical and empirical knowledge and classroom practice" (Vosniadou, 2008: xix).

How can we teach for conceptual change?

So the lack of consensus over how personal concepts should be understood, how to represent conceptual structure, and how to model conceptual change, does not bode well for those hoping research in this area can inform teaching. Teachers may not be encouraged to be told that "the conceptual system seems to be non-linear – under many circumstances, even a great deal of instruction can lead to little change, while in other situations small influences can lead to major insights" (Brown & Hammer, 2008: 138). So it is suggested that what might seem to an observer as a simple shift in a student's preferred explanations may involve "*concurrent and inter-related* changes in concepts…conceptual relations…, ontology and epistemology" (Wiser & Smith, 2008: 207). Given this, it is not surprising that one chapter warns that "it is naïve to assume that any educational practice can be shown to be straightforwardly 'better' than other practices… because decisions at a very fine grain size can make a very significant difference to students' conceptual learning following teaching" (Leach & Scott, 2008: 670).

Despite such warnings, there certainly are some claims in *this Handbook* that can inform authors of instructional material and teachers. Chi's work suggests that there is little point challenging some alternative conceptions in physics, for example, as what is needed are new starting points that better fit with the ontology of the scientific concepts we want students to 'acquire'. Teachers can read about a range of research findings demonstrating effective curriculum strategies and classroom tactics, such as studies that "demonstrated the importance of eliciting student ideas about scientific phenomena before engaging them in experimentation and asking students to make predictions before they conducted experiments" (Linn, 2008: 706), and the related Hypothesis-Experiment-Instruction instructional approach (Miyake, 2008: 469), which seems to be an elaboration of the well-known POE (predict-observe-explain) approach (White and Gunstone 1992).

A number of chapters warn of problems with teaching through setting up cognitive conflict/ dissonance, because although "the brighter, more successful students reacted enthusiastically to 'cognitive conflicts', the unsuccessful students developed negative attitudes and tried to avoid conflicts" (Clement, 2008: 423). The use of pivotal cases (Linn, 2008: 702) and bridging analogies (Brown & Hammer, 2008) are discussed, and readers are told how complementary "multiple analogies were significantly more effective than single analogies" (Clement, 2008: 428). There is advice about the role of quantitative work in learning physics, both in terms of the value of mathematical insights in understanding the physical concepts (Wiser & Smith, 2008), and the importance of deferring quantitative problems until students are able to handle and apply concepts qualitatively (Brown & Hammer, 2008; Jonassen, 2008). There seems to be a double problem here – the absence of sufficient mathematical language, symbolism and representation in teaching physics topics in lower grades, and the tendency with older students to introduce concepts and then move straight to exercises involving little more than algebraic manipulation, with limited attention to the physical meaning of the symbols.

The value of whole class dialogue is considered (Vosniadou et al., 2008), as is the use of group work, which can be valuable as long as the groups are "well-functioning" so that "their discourse environment offers distributed memory, alternative interpretations, multiple candidate structures, and a focal point for coordinating their efforts" (Schwartz et al., 2008: 497). Such group work can aid in the eliciting and sharing student ideas, which has been shown to be valuable "even if students never innovate the correct outcome themselves" (Schwartz et al., 2008: 496).

Although "the strongest effects on knowledge or beliefs resulted from interventions that directly addressed, in some way, students' initial understandings [rather than] approaches that focused more on the presentation of accurate scientific information with less attention to students' current understandings produce more modest effects" (Murphy & Alexander, 2008: 612), the reader is also told that even when teachers engage in elicitation of student ideas, too often such ideas are not then drawn upon dialogically in the subsequent teaching episodes (Duit, Treagust et al. 2008). The readers is also warned that approaches which bring about the best long-term learning gains are often those which lead to more short-term dips in performance (Linn, 2008: 712). There is much here, then, which is research-based, and can inform teachers, and which does seem more clear-cut than the underlying theoretical perspectives adopted in research.

The focus on the sciences

A number of the contributors to this volume note how much work in conceptual change has been located in science learning contexts. One chapter reports that "conceptual change, as a field of study, tends to be nested within scientific domains, particularly the physical sciences" (Murphy & Alexander, 2008: 597). The impression given by *the Handbook* is that much research is based in physics, but also that biology is well represented. This raises as issue about whether we should expect conceptual change to be much the same regardless of the domain in which we are interested. Indeed, the findings from some of the work in biology suggest a pattern that almost seems to reflect something like a Piagetian conceptual development model where "conceptual change in naïve biology takes place approximately between the ages 5 and 10 years" (Inagaki & Hatano, 2008: 241-242) and learning about natural selection shows "two age-related shifts: from the mixture of spontaneous generation and creationist ideas found in the 5- to 7-year-olds to the consistent creationism of the 8- to 9-year olds; and the second shift to the endorsement of evolutionary ideas among early adolescents, at least in the non-fundamentalist communities" (Evans, 2008: 273). Evans suggests that a characteristic of biology which influences such shifts is that unlike the physical sciences, biology is concerned with ultimate (as well as proximate) causes.

The chapter discussing research into learning in medicine offers a somewhat different impression, as here the focal issue of concern is not about concept acquisition, but of application, i.e. how medical students transfer their theoretical knowledge into practical contexts. It is suggested that the mental models students have developed are 'too brittle' for ready application (Kaufman, Keselman, & Patel, 2008: 307). Medical students are somewhat different (in age, motivation, ability) to typical school students, but according to Kaufman, Keselman & Patel's review, they show the same types of learning impediments as are found when examining younger students' thinking about their school science (Taber 2009): missing prerequisite knowledge; misinterpreting teaching; fragmented knowledge structures; creative-but-inappropriate analogical learning and so forth.

Much work has been done on learning in physics, and contributors such as diSessa, Hammer and Chi are well known for their studies in this context. The latter, strangely for someone who emphasises how ontological misclassifications can be critical in physics learning refers to 'heat' as being "the *speed* of molecules" (Chi, 2008: 73): apparently making an ontological category error both conflating (a) heat and temperature and (b) macroscopic phenomena and theoretical submicroscopic models.

Much less work seems to have been undertaken in chemistry contexts. The chapter in *the Handbook* that explores learning about the nature of matter (a prerequisite for all later chemistry learning) may offer a clue in its claim that the 'basic tenets' of the "atomic-molecular theory… are few and simple. All matter is made up of atoms, which are far too small to see through an optical microscope. There is empty space (vacuum) between atoms. Each atom takes up space, has mass, and is in constant motion" (Wiser & Smith, 2008: 218). Each of these three statements is actually far from being simple (Taber 2003). 'All matter is made up of atoms' is a slogan of school chemistry, when actually very few materials actually contain discrete atoms - which are more usefully considered as a heuristic accounting device than the actual 'building blocks' of matter. Arguably, the notion of the vacuum is a macroscopic/molar one which does not apply in any meaningful sense on the scale of molecules. Also, if atoms took up space in the way macroscopic objects do, it would not sometimes be possible for them to overlap and share the same space in just the way familiar physical objects such as billiard balls do not! There are studies in the literature on conceptual development in chemistry, but in some ways understanding conceptual learning in chemistry has proved to be more complex and challenging than in either physics or biology (Taber and García Franco 2010). Perhaps if there is a new handbook on conceptual change in another decade, then a chapter on studies in more advanced chemical topics might provide a useful contribution.

The research agenda

At the end of *the Handbook*, the reader is left wondering whether apparently different models emerging from different disciplines and topics primarily reflect those different contexts, or more the different assumptions and perspectives the researchers concerned import into their work. Brown and Hammer's (2008) call for different levels of analysis is significant here. The reader of *the Handbook* is informed that "variability of learning tends to be high; children learn via different paths, at different rates, and with differing degrees of generalization. Finally, certain sources of cognitive growth, such as encouragement to explain observations of physical phenomena or other people's reasoning, operate over a wide age range and in diverse content domains" (Siegler & Svetina, 2008: 105). Yet, the "prevailing models of conceptual change are presumed to depict the nature or process of change broadly…we are presented with generic models that speak to conceptual change in (a) any content (b) for all learners (c) at any point in their academic development" (Murphy & Alexander, 2008: 607). Murphy & Alexander ask why so much of the research has been limited to science learning concepts, a point echoed by White & Gunstone (White and Gunstone 2008).

A key message from the book then is that there is a great deal more to be learnt. However, there are also strong suggestions for how research should proceed. diSessa (2008: 55) argues that "a good tracking of concepts and conceptual change necessarily entails an extensive accounting at a sub-conceptual grain size. We must necessarily say a lot about intuitive mental ecologies to account for their properties and to account for the emergence of new concepts". Such studies are, he claims "almost non-existent" (p.47). However Sigeler and Svetina (2008) warn that the nature of microgenetic studies (where individuals are subject to frequent, close scrutiny – inevitably an intervention in the normal course of learning) makes them questionable as models of normal development. This is so, but such models need to be developed first, to identify potentially useful patterns indicative of conceptual change, that can then be tested among more typical populations using survey methodology. Advances in such areas will require iterative swings of the methodological pendulum between the in-depth study of the individuals that can provide detail and give insight to mechanism, and the testing of ideas among representative populations and in 'typical' classrooms (Taber 2009). Linn (2008: 716) warns that "an important methodological issue concerns reporting all the ideas that students have. Some researchers minimize this issue by attempting to identify one most salient idea [which] neglects important views that students may use effectively in different contexts or could use to improve their interpretation of complex settings". Likewise, diSessa argues that "the mere fact of students' use of multiple models is downplayed in most coherence research, and it is not the focus of systematic empirical study" (diSessa, 2008: 49). This is certainly one area where it has been found that chemistry learning may provide useful contexts (Taber 2000).

Concluding comments

The *International Handbook of Research on Conceptual Change* offers a wealth of ideas, from a range of perspectives, drawing on a diverse literature. It should be an essential resource for anyone working in the fields of learning and conceptual development as researcher or advanced student. With much of the work discussed relating to science concepts, the book has a great deal of offer to anyone in the field of science education. Taken as a whole, it offers more questions than answers, and is certainly more a book for the researchers than the teacher – although the latter can find much of interest. Research students looking at learning in science should consider purchasing a personal copy, because this is a book should prove an invaluable aid to their work. Indeed, the chapter by Brewer (2008) offers an excellent introduction to approaches to research into student thinking that should find its way onto a great many reading lists. Vosniadou has put together a volume of complementary, but sometimes contradictory, and often inconclusive, accounts of the state of knowledge in the field of conceptual change. By the same token, she has managed to compile an excellent resource to inform the next generation of researchers who may move the field forward, so that perhaps a future handbook may be able to offer a more consistent and coherent account. It is certainly a fascinating volume, and is highly recommended for anyone with an interest in the topic.

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